THE EFFECT OF INTENSIVE VACUUMING ON INDOOR PM MASS CONCENTRATION

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ABSTRACT

A study was conducted in 36 carpeted homes over 14-weeks to investigate the impact intensive vacuuming has on indoor particulate levels. Intensive, high efficiency, vacuum cleaning, was carried out in 19 homes while 17 were monitored as controls. The intervention reduced airborne PM mass concentration by approximately 50% ($P<0.01$). PM_{10} and $PM_{2.5}$ mass concentration at the end of the intervention and monitoring program were similar to outdoor concentrations at approximately 21µg m^{-3} and 14µg m^{-3} respectively. PM mass concentration did not increase once vacuuming intensity (duration of cleaning event) was reduced. No significant changes were seen in the control group during the course of the monitoring period.

The results suggest one intense clean (4min m^{-2} carpet) followed by regular moderate intensity cleans (1min m^{-2} carpet) can substantially reduce the amount of material entrained in carpet and reduce the potential for PM re-suspension resulting in near ambient airborne PM mass concentrations.

INDEX TERMS

Particulate matter, Vacuuming, Carpet, Asthma

INTRODUCTION

In terms of air pollutants, particulates are considered by many to be one of the biggest threats to human health (Jones, 1999). Irritation of the eyes, nose and throat, fatigue, headaches and nausea are all common conditions that, in the indoor environment, have been widely attributed to exposure to PM (Dingle and Smith, 1994, Brown, 1997).

The indoor environment is host to a diverse range of particles, many of which have or at some point in time will be suspended in the air. Most particles adhering to indoor surfaces were likely suspended in the air at some time. Particles found on flooring consist of a broad assortment of particles from all PM sources, with soil and fibre constituting a high proportion of the mass present.

Several studies have found that within homes carpets are potentially the largest and most common reservoirs of PM (Hansen and Burroughs, 1999). Carpets have been shown to contain specific PM species years after sources were removed (Camann *et al*., 1990). From a respiratory focus, problematic indoor PM species include: combustion particulates, pollen, spores, fungi, mould animal fibres, insect body parts, dog, cat, dust mite and cockroach allergen and epithelial cells (Owen *et al*., 1990), all of which can accumulate in carpet.

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Unlike hard-floors, carpet tends to act as a suppressant of dust and dirt, limiting re-suspension to areas directly affected by activity, whereas dust on hard-floors is more easily re-suspended. Such behaviour is likely to be a result of the fibrous nature of carpet. The amount of dirt and dust available for re-suspension in carpet is a function of maintenance. A well-maintained carpet, that is one regularly cleaned, has lower levels of particle accumulation and less potential for particle re-suspension (Schneider *et al*., 1993, Kildeso *et al*., 1999).

The frequency and duration of carpet cleaning needed to avoid particle re-suspension is unclear and is likely to be impractical. Limiting particle re-suspension to a certain threshold considered 'healthy' is a more likely outcome. A consideration in carpet cleaning is the equipment used and the frequency and duration of cleaning events. High performance filtration vacuum cleaners are currently the only machines capable of efficiently removing dust from carpets whilst not significantly re-suspending fine PM (Franke *et al*., 1997, Kemp *et al*., 1998).

This study sets out to examine whether high to moderate intensity vacuum cleaning using a high performance vacuum cleaner results in reduced indoor PM mass concentration.

METHODS

Participants were recruited through local primary schools within an area of $40km^2$. Seventeen participants were assigned to a placebo group (referred to as the control group) while 19 were assigned to the intervention group (referred to as the vacuum group). Allocation to any group was random, however geographic distribution needed to be approximately equal; this was achieved by clustering the location of participants on a map.

Over 14 weeks, starting in April 2000, participants of the vacuum group had their house vacuumed fortnightly with a high efficiency Filter Queen™ HEPA vacuum cleaner. Fabric upholstered sofas and the participant's bed was also vacuumed at $1min\ m^{-2}$. Participants of the control group had a Defender™ air filter placed in their bedroom with the filter media removed.

Before vacuuming commenced a plan of each home was made. The plan detailed the dimensions (mm) of each carpeted room and areas not to be vacuumed within the rooms, for example under heavy furniture. Using the plans, each home was vacuumed for $4min\ m^{-2}$ for the first cleaning event, $2min\ m^{-2}$ for the second event and $1min\ m^{-2}$ for the remaining five cleaning events.

Monitoring of participants bedrooms took place between 11am and 7pm, 4hrs during and 4hrs after school. Each bedroom was monitored five times during the 14-week period, monitoring did not take place during the 4^{th} and 6^{th} cleaning event. Each monitoring cycle spanned several weeks. Some homes were monitored both indoors and outdoors. Mass concentration was determined via time weighted gravimetric analysis. Using a TSI Respicon™, three size fractions of airborne particles were simultaneously collected onto individual filters, $PM_{2.5}$, PM_{10} and PM_{TI}; where PM_{TI} refers to total inhalable particles. Two intermediary size fractions were also quantified: PM_{TB} and PM_{ET}; PM_{TB} refers to particles likely to be captured in the Tracheobronchial region of the respiratory system (>12.5 < 10 microns) and PM_{ET} to particles captured in the extra-thoracic region (>10 microns). Respicon's were coupled to SKC Aircheck™ (224-PCXR8) sample pumps: calibrated to $3.11L\ min^{-1}$ using a 1-litre soap film calibration tube. Monitoring equipment was set-up before 10am. The equipment was placed approximately one metre from any wall, with the sample head one metre above the ground and at least two metres from an air filter. Pallflex Emfab™ TX40H120 filters were used in the Respicon's.

Weighing of filters took place in a humidity controlled (RH<40%) 'balance room' with an air temperature variation of less than 3°C. Filters were weighed on a six-figure Sartorius™ 4g micro-balance. Before being weighed, filters were conditioned for at least two-hours, both before and after use. The balance was calibrated weekly and filter blanks regularly used to ensure weighing accuracy. The weight of the filters before and after sampling was determined and the mass concentration of each size fraction calculated as per instrument specifications.

Statistical analysis was undertaken using paired t-test and ANOVA with a CI of 95%.

RESULTS

No significant variations were observed across the initial data set for all: $PM_{2.5}$ (P=0.39); PM_{10} (P=0.31) and PM_{TI} mass concentrations (P=0.27), indicating that despite each monitoring cycle spanning several weeks, the mass concentration for each size fraction of the weekly sub-sets, was similar.

Over 500 mass concentration samples were collected during the intervention. No significant fall, in any size fraction, was detected in the control group when paired first and last values were compared (P ≥0.05). Significant falls in all size fractions of the vacuum group were seen when, paired, first and last vacuum results were compared. Over a 14-week period, mean PM_{TI} mass concentration was reduced by approximately 48%, PM_{10} by 49% and $PM_{2.5}$ by 40%. PM_{TB} and PM_{ET} fell by 60% and 74% respectively.

Table 1 summarises the changes in PM mass concentration between the first and last monitored paired data. For example in the control group before vacuuming took place, mean concentration for the PM_{TI} size fraction was 44μg m^{-3}, during the course of the intervention it fell to 35g m^{-3}.

The largest fall in PM concentration occurred in the vacuum group after the first cleaning event. While most of the fall in PM mass concentration occurred as a result of the first clean, for example PM_{TI} fell from 68μg m^{-3} to 37μg m^{-3}, further significant decrease also occurred between the first and last cleaning event, for example PM_{TI} fell from 37μg m^{-3} to 31μg m^{-3}.

The intervention was more effective at reducing the concentration of coarse PM (65%) rather than fine PM (40%). Coarse PM consists of PM_{TB} (>2.5μm <10μm) and PM_{ET} (>10μm).

Table 1 Mass concentration of PM and statistical significance in vacuum and control homes.

PM size fraction	Control homes μg m^{-3}		Vacuum homes μg m^{-3}	
	Pre-monitor	Last monitor	Pre-monitor	Last monitor
PM_{TI}	44	35 (P=0.09)	68	31 (P<0.01)
PM_{10}	32	27 (P=0.15)	45	22 (P<0.01)
$PM_{2.5}$	19	19 (P=0.49)	25	14 (P=0.03)
PM_{TB}	13	8 (P=0.07)	20	8 (P<0.01)
PM_{ET}	13	8 (P=0.05)	23	6 (P<0.01)

Ninety-eight paired sets of samples were collected concurrently in the bedroom and outdoors. Mean PM mass concentrations were higher indoors than outdoor. Unlike the control group, indoor PM mass concentrations fell to near ambient mass concentrations in the air-filter group.
Mean mass recovery from the first clean (duration 4min m^{-2}) was 11.7g m^{-2} of carpet, mean recovery from the second clean (duration 2min m^{-2}) was approximately half at 5.9g m^{-2} and mean recovery from the third clean (duration 1min m^{-2}) was approximately half again at 2.8g m^{-2}. Thereafter, further fortnightly vacuum cleaning at 1min m^{-2} resulted in a gradual decrease in the mean mass recovery to approximately 1.9g m^{-2}. Statistical analysis of the falls in mass recovery show significant falls between the first three cleans and the third and last clean ($P<0.001$).

DISCUSSION

The vacuum intervention significantly reduced the PM mass concentration ($P\leq0.03$) while control values remained statistically unchanged. The percentage reduction of each size fraction suggests that one intense vacuum of 4min m^{-2} of carpet followed by regular moderate intensity vacuuming of 1min m^{-2} of carpet can reduce PM mass concentration across all size fractions and in particular the coarse fraction.

Na's study (1999) also using a Filter Queen™ vacuum cleaner but with a duration of 6min m^{-2}, as opposed to 4min m^{-2}, saw a reduction in airborne PM_{10} and $PM_{2.5}$ mass concentration of 73% and 60% respectively, after one clean. Kemp *et al*., (1998) observed an 80% reduction in airborne PM mass concentration in a Perth office building after conventional carpet vacuuming was replaced with high efficiency vacuuming. In other studies a significant proportion of aeroallergens such Fel d 1 and Der p 1 were detected in association with particles larger than 5µm (de Blay *et al*., 1998). It is therefore likely that a reduction of more than 60% of airborne particles larger than 2.5µm will result in a significant reduction of aero-allergenic particles.

Much of the change in airborne mass concentration occurred after the first high intensity vacuum clean. Thereafter, moderate intensity vacuuming resulted in a modest, but statistically significant, fall in all PM size fractions, culminating in indoor PM mass concentrations similar to the mean outdoor PM mass concentrations. For example, indoor mean PM_{TI} and $PM_{2.5}$ mass concentrations were 30µg m^{-3} and 14µg m^{-3} respectively, whereas outdoor mean PM mass concentrations for the same size fractions were 31µg m^{-3} and 11µg m^{-3} respectively.

This study found the reduction in airborne PM mass concentration was associated with a reduction in the quantity of particulates trapped within carpet, likewise Ragsdale *et al*., (1995) found that airborne PM mass concentrations were reduced when corresponding surface PM concentrations were reduced. Franke *et al*., (1997), Leese *et al*., (1997), Kemp *et al*., (1998), Kildeso *et al*., (1998) and Lioy *et al*., (1999) all demonstrated that cleaning with high efficiency vacuum cleaners as opposed to conventional vacuum cleaners could significantly reduce airborne PM concentration.

CONCLUSSION AND IMPLICATIONS

The vacuum intervention significantly reduced the aerosol PM mass concentration of all size fractions to near ambient concentrations thereby reducing the potential for PM exposure and inhalation. The intervention was most effective at reducing the coarse particles (>2.5µm), which are typically associated with aero-allergens.

The reduction in aerosol PM mass concentration was associated with a reduction in surface mass concentration; however no direct correlation was observed between the reductions. Other studies also found that airborne PM mass concentrations were reduced when corresponding surface PM concentrations were reduced but that the relationship between surface and suspended dust concentrations was not simple, or easily quantified.

This study demonstrates that significant reductions in aerosol PM mass concentration can be achieved by one intense high efficiency vacuum clean followed by regular moderate intensity (1min m^{-2}) high efficiency vacuum cleaning. Such measures are likely to ameliorate the ‘sink & source’ effect of carpet and be of benefit to those who suffer from hypersensitivity of the respiratory system.

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